Introduction to Systems Engineering
Awareness Seminar
SESGE-AEIS/INCOSE

Escuela Politécnica Superior
Universidad Carlos III de Madrid

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INCOSE Vision

Promote SE research and organizational investment

Align SE initiatives, including SE research, SE standards, methods, tools, and curriculum

Identify SE capabilities to support future challenges and needs

Broaden the base of practitioners across industry domains
About the instructor
Contents

• What is a system?
• What is systems thinking?
• What is systems engineering (SE)?
• Why is it important?
• Background and history
• What are the Technical SE Process and the Vee-Model approach?
• What is the System Life Cycle?
• Requirements, Architecture, Verification, Validation and Testing
• Applied standards (ISO15288: 2015), techniques and SE management.
• Trends
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**Integrative Systems Science**
Identifying, exploring, and understanding patterns of complexity through contributions from

- **Foundations**
  - Meta-theories of Methodology, Ontology, Epistemology, Axiology, Praxiology (theory of effective action), Teleology, Semiotics and Semiosis, Categories, etc.

- **Theories**

- **Representations**
  - Models, Dynamics, Networks, Cellular Automata, Life Cycles, Queues, Graphs, Rich Pictures, Narratives, Games and Dramas, Agent-based Simulations, etc.

**Systems Thinking**
Appreciative and reflective practice using 'systems-paradigm' concepts, principles, patterns, etc.

**Systems Approaches to Practice**
Addressing complex problems/opportunities using methods, tools, frameworks, practice patterns, etc.

- **Pragmatic, Pluralist, or Critical multi-methodology**
  - Uses heuristics, prototyping, model unfolding, boundary critiques, etc., to understand assumptions, contexts, and constraints, including complexity from stakeholder values and valuations; chooses appropriate mix of 'hard', 'soft', and custom methods; sees systems as networks, societies of agents, organisms, ecosystems, rhizomes, discourses, machines, etc.

- **'Hard' methods** are suited to solving well-defined problems with reliable data, clear optimization goals, and at most objective complexity; use machine metaphor and realist/functionalist foundations.

- **'Soft' methods** are suited to structuring problems involving incomplete data, unclear goals, perspective and role complexity, etc.; use learning system metaphor and constructivist/interpretivist foundations.

Input from experience and legacy practices
Solicited local values, knowledge, etc.

Direct input from disciplines
Measured and specified data, metrics, etc.
Seeing the world in a particular way, because how you see things affects the way you approach situations or undertake specific tasks.
A definition of System

A system is a group of interacting, interrelated, or interdependent elements forming a complex whole.

System of Interest is the system of concern to those who have interest in it.
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Powerful approach to problem analysis

Systems thinking provides a very powerful approach to problem analysis that gives analysts the ability to view problems within the context of an overall system, and thereby better identify and prevent unintended negative consequences of proposed solutions (changes).
Systems thinking is the process of understanding how things, regarded as systems and components of systems, influence one another within a whole. Focused on the entire system and how the parts interrelate.

“Dividing a cow in half does not give two smaller cows”
A broader view of the world

Systems Engineers practically apply systems thinking to understand Who, When, Where, What, How and Why

Appreciate the interconnectedness of all things
Problem vs Solution

What we dream up at kickoff:
- Titanium-plated nose cone
- Commemorative custom artwork
- Titanium fins (x4)
- Long range supersonic antenna
- One way mirror viewport
- Plutonium-fueled twin side boosters
- Nickel-plated rakers

What we settle for at launch:
- Nose cone
- Antenna
- Single booster
- Fins

What the user needs:
- Bike
- Ramp

Who, When, Where, What, How and Why
Focused on the entire system and how the parts interrelate

Why
Understand principles, what is best?

How
Understand patterns

What
Understand rules

Who, When, Where

DATA
Index

INFORMATION
Rules

KNOWLEDGE
Model

WISDOM
Vision
Four dimensions for attacking a problem

**Information**
- To confront yourselves with the need situation by approaching users
- To collect information about existing solutions and products

**Problem**
- To compile a new product design specification by modifying the old one

**Solution**
- To synthesise a number of alternative solutions
Four dimensions for attacking a problem

Information

Problem Space
About NEEDS

QUESTIONS

Solution Space
About the offerings that satisfy NEEDS

ANSWERS

Knowledge

To confront yourselves with the need situation by approaching users
To compile a new product specification by modifying the old one
To synthesise a number of alternative solutions
Full creativity of the team

It is very difficult for people describing requirements to avoid jumping to solutions instead of describing needs.

This constrains the team in realizing the optimal solution and fails to employ the full creativity of the team.
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Common Misconception

Systems Engineering (SE) is a narrow branch of engineering associated with computers, software, and information technology (IT).

Clarification

• **SE is a very broad**, overarching, and generally applicable engineering discipline. Many types of systems are developed using SE. These include biomedical systems, space vehicle systems, weapon systems, transportation systems, and so on.

• **SE involves the coordination of work** performed by engineers from all other engineering disciplines (electrical, mechanical, computer, software, etc.) as required to complete the engineering work on the project/program.

Demand is soaring for Systems Engineers

Drewimations.com - 23
Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal.

Systems Engineering (SE) considers both the business and technical needs of all customers with the goal of providing a quality product that meets the user needs.”

(INCOSE SE Handbook)
Meta-Discipline that integrates technical effort across the Development Project

• Functional Disciplines
• Technology Domains
• Specialty Concerns
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Systems Engineering needed due to product complexity is increasing

- High Complexity
- Multidisciplinary
- Cost
- Time
Different views of the same Problem
(System = Elephant)

@bernardo
Why Systems Engineering?

Commitment to technology, configuration, cost etc

Cost incurred

System specific knowledge

 Ease of change

Concept & prelim. design

Detail design & development

Production

Use, phase-out disposal
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## Origins of SE

<table>
<thead>
<tr>
<th>Year</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1937</td>
<td>British multidisciplinary team to analyze the air defense system</td>
</tr>
<tr>
<td>1939-45</td>
<td>Bell Labs supports NIKE development (1st US operational anti-aircraft missile system)</td>
</tr>
<tr>
<td>1951-80</td>
<td>SAGE (Semi-automatic Ground Environment) Air Defense System defined and managed by MIT/Jay Forrester</td>
</tr>
<tr>
<td>1956</td>
<td>Invention of systems analysis by RAND corp.</td>
</tr>
<tr>
<td>1960-70</td>
<td>Apollo Program First SE standards (e.g. MIL-STD 499, NASA procedures)</td>
</tr>
<tr>
<td>1962</td>
<td>Publication of Arthur D. Hall – A Methodology for Systems Engineering</td>
</tr>
<tr>
<td>1989</td>
<td>EIA recognizes SE as important part of system development</td>
</tr>
<tr>
<td>1990</td>
<td>NCOSE is founded</td>
</tr>
<tr>
<td>1990-2000</td>
<td>Release of SE standards IEEE 1220, EIA 632</td>
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<tr>
<td>1994</td>
<td>NCOSE renamed to INCOSE</td>
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<tr>
<td>2002</td>
<td>Release of ISO/IEC 15288</td>
</tr>
<tr>
<td>2008</td>
<td>App. 6500 INCOSE members worldwide</td>
</tr>
<tr>
<td>2019</td>
<td>17000+ INCOSE members worldwide (70+ Chapters 35+ Countries)</td>
</tr>
</tbody>
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Technical SE Processes

Technical Processes

Business or Mission Analysis Process
Stakeholder Needs & Requirements Definition Process
System Requirements Definition Process
Architecture Definition Process
Design Definition Process
System Analysis Process
Implementation Process
Integration Process
Verification Process
Transition Process
Validation Process
Operation Process
Maintenance Process
Disposal Process

TECHNICAL PROCESSES

Systems Analysis
Transition
Maintenance
Disposal
Operation
Validation
Integration
Implementation

Business or Mission Analysis
Stakeholder Needs & Requirements Definition
System Requirements Definition
Architecture Definition
Design Definition
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**Life Cycle**

*Life Cycle* is the evolution of a system, product, service, project or other human-made entity from conception through retirement.


A *life cycle for a system* generally consists of a series of stages regulated by a set of management decisions which confirm that the system is mature enough to leave one stage and enter another.

( SEBoK Version 1.9.1 2018 )
Life Cycle Stages & Decision Gates

Exploratory
- Investigate new opportunities
- Explore technology readiness
- Evaluate pre-concept match with users’ needs

Concept
- Identify stakeholders needs
- Evaluate alternate concepts
- Recommend possible solutions

Development
- Develop detailed planning
- Identify and manage risks
- and business opportunities
- Perform IV & V activities

Production
- Produce systems
- Inspect and Test

Utilization
- Operate system to satisfy users' needs

Support
- Provide sustained system capability

Retirement
- Store, archive or dispose of system

ALTERNATIVE DECISION GATE OUTCOMES
- Proceed to next stage
- Proceed but open action items must be resolved
- Not ready; repeat the previous stage
- Terminate the project
Comparisons of Life Cycle models


Typical High-Tech Commercial Systems Integrator

Typical High-Tech Commercial Manufacturer

US Department of Defense (DoD) 5000.2

NASA

US Department of Energy (DoE)
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System Architecture is abstract, conceptualization-oriented, global, and focused to achieve the mission and life cycle concepts of the system.
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Logical and physical models (or views) are often used for representing fundamental aspects of the system architecture.
Requirement

A requirement is “a statement that identifies a system, product or process characteristic or constraint, which is unambiguous, clear, unique, consistent, stand-alone (not grouped), and verifiable, and is deemed necessary for stakeholder acceptability.”

(INCOSE Systems Engineering Handbook)
System Requirements

System requirements are all of the requirements at the system level that describe the functions which the system as a whole should fulfill to satisfy the stakeholder needs and requirements, and is expressed in an appropriate combination of textual statements, views, and non-functional requirements; the latter expressing the levels of safety, security, reliability, etc., that will be necessary.

System requirements play major roles in systems engineering, as they:

- Form the basis of system architecture and design activities.
- Form the basis of system integration and verification activities.
- Act as reference for validation and stakeholder acceptance.
- Provide a means of communication between the various technical staff that interact throughout the project.
**Verification** ensures you built the system right

**Validation** ensures you built the right system

V&V in Requirements, Design, System

( INCOSE SE Handbook )
V & V Requirements

Requirement Verification: ensuring the requirement meets the rules and characteristics defined for writing a good requirement. The focus is on the wording and structure of the requirement.

Requirement Validation: confirmation that the requirements and requirement set is an agreed-to transformation that clearly communicates the stakeholder needs and expectations in a language understood by the developers.

System Verification: a process done after design and build or coding, ensuring the designed and built or coded system meets its requirements. The focus is on the built or coded system and how well it meets the agreed to requirement set that drove the design and fabrication.

Methods used for system verification include: test, demonstration, inspection, or analysis.

“Did we build the thing right?”

V & V System

System Validation: a process that occurs after system verification that confirms the designed, built, and verified system meets its intended purpose in its operational environment.

The focus is on the completed system and how well it meets stakeholder expectations (needs) that were defined during the scope definition phase that should have occurred at the beginning of the project.

“Did we build the right thing?”

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Harmonization

ISO/IEC/IEEE 15288

NATO AAP-48

EIA 632

SEBoK

Cooperative Technical Co-evolution

SEBoK Joint Governance Board

SEBoK Joint Editorial Board (SERC/INCOSE/IEEE)

INCOSE KM WG

INCOSE WGs

CAG

DoD SE Refs (DAG: Ch 4, Sys Assurance, SoSE)

Maintain (SEBoK Knowledge Areas/Working Groups)

Maintain

SEH evolutions through new versions

SEBoK evolutions gathered through Wiki

Influence evolution

Influence evolution

Drives lower level standards and user documents

Drives SE Certification

INCOSE SE Handbook

INCOSE Community of Users

Propose evolution through comments
Manage the project and the relationships

- **Enabling Processes (Business & Organization)**
- **Management Processes (Project)**
- **Technical Processes**

Other Organizations
ISO 15288 Processes
Moving from Document-Centric to Model-Centric

Today
standalone models related through documents
Still Document-Centric

Future
shared system model with multiple views, and connected to discipline models

Traditional
- Specifications
- Interface requirements
- System design
- Analysis & Trade-off
- Test plans

INCOSE Model-Based Systems Engineering Workshop, February 2010. Copyright © 2010 by INCOSE. All rights reserved.
What is Model-Based Systems Engineering (MBSE)?

MBSE is the formalized application of system modelling techniques to support the product development.

It includes analysis of the system context, the development of system requirements, design of the system architecture and continuous system validation applied to all systems engineering activities.

Improved:

- Product quality
- Management of product complexity
- Communication of designs and stakeholders
- Knowledge capture and re-use
Individual Competence Leads to Organizational, System & Operational Capability
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Challenging Complex Projects
Increasing Rate of Technology Adoption
Complex Global Trends

Human Needs translate to...

Societal Needs that are satisfied by...

System Solutions
Increasing Complexity of System Solutions

Number of Components
Number of Functions
Number of Interactions

Systems Engineering Tools

5000 BC  1200 AD  1750 AD  1850 AD  1900 AD  1980 AD  2010 AD
Need to adapt SE approaches

- Tailored to the domain
- Scaled to project size
- Scaled to system complexity

Need for agility
Creating Systems that work

1. Debate, define, revise and pursue the purpose / need
2. Think holistically
3. Follow a systematic procedure
4. Be creative
5. Take account of the people
6. Manage the project and the relationships

Creating Systems that work

1. Debate, define, revise and pursue the purpose / need Life cycle phases and long-term view
2. Think holistically systems thinking
3. Follow a systematic procedure SE processes
4. Be creative divergent thinking
5. Take account of the people multidisciplinary integration
6. Manage the project and the relationships management

Come and join INCOSE

Professionals, students and young graduates are welcome
Thank You